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Advanced GPS Technologies (AGT)

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Report Documentation Page

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Bottom Line Up Front

Briefing Purpose: Inform Partnership Council about AFRL technology investments to improve affordability and performance of the GPS Space Segment

Summary

- Working in close partnership with the GPS SPO to develop advanced technology options for future satellites
- Focus is on technologies with greatest payoff for our warfighters and the system
  - We're finding problems/risks now and solving/reducing them to minimize "technology discovery" during system development

Exploring/opening paths to the future!

AFRL Investments Supporting GPS Space Segment

- AFRL is investigating science and technology **options** for future GPS spacecraft (PNT Payloads and satellites)
  - To provide timely and cost-effective maturation of new technologies
    - Requirements pull (responding directly to identified AFSPC needs)
    - Tech Push
  - To enable
    - Improved performance
    - Reduced size, weight, power, and cost
    - Increased flexibility and resilience
    - Improved manufacturability
    - New concepts, architectures, and/or capabilities

GPS III

Developmental Optical Clock

Deployable Antenna Concept

Science and Technology for GPS Spacecraft

- AFRL has funded a portfolio of projects supporting next generation GPS spacecraft

Technologies	Capabilities
High efficiency GaN amplifiers On-orbit Reprogrammable Digital Waveform Generators New antenna concepts Supporting electronics Algorithms and new signal combining methods Satellite bus technologies for lower SWaP/ increased resiliency Advanced cyber technology	Lower-SWaP spacecraft OR higher power signals Increased signal flexibility after launch Lower cost OR increased capability payload Increased signal strength Information assurance designed-in from the start

SWaP = Size, Weight, and Power

Advanced L-Band Amplifier Technology for GPS

Objective:

- Design, fabricate, and characterize performance of advanced L-band power amplifier engineering development units
  - Space qualifiable/suitable for GPS

	Threshold	Objective
Increased η (%)	45%	60%
Increased Power (W RF_{out})	250	400

Payoff:

- Lower S/C power required for same signal strength
  - Less mass/cost for power system
- Reduces waste heat for same signal strength
  - Enables denser layout, decreases thermal subsystem requirement
- Increased signal strength for anti-jam
- Decrease part count in boxes

Acquisition Status:

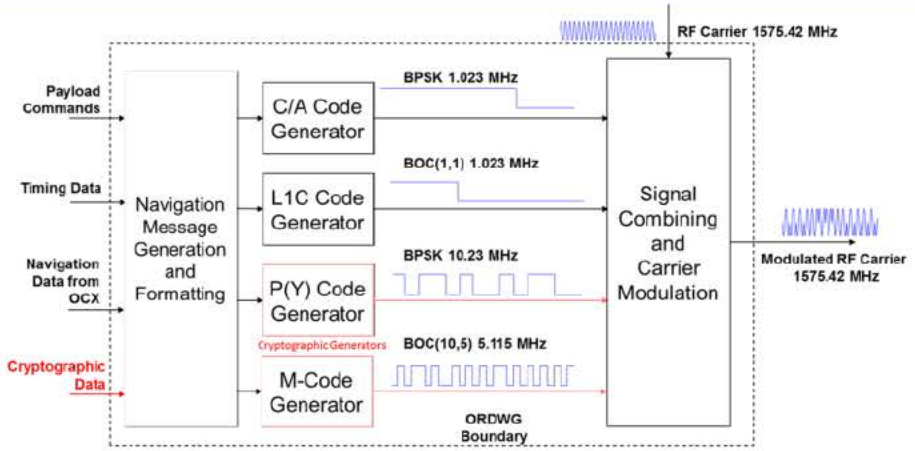
- Three contracts awarded in June 2014
  - Ball, $2.1M
  - Boeing, $4.5M
  - Northrop Grumman, $1M

On-Orbit Reprogrammable Digital Waveform Generator Project

Develop & Demonstrate TRL 5+ technology to digitally produce GPS Signals

Payoff / Benefits

- Reprogrammable on orbit
  - Enables on-orbit up-dates/additions to waveforms
  - Enables shifting of power between modulations.
  - Enables pre-correction of signals
- Improves performance
  - Increased position/time accuracy
- Reduces part count, complexity, & expense
- Reduces mass & power consumption
- Reduces payload integration risk and schedule



Functions of an L1 band On-Orbit Reprogrammable Digital Waveform Generator

Status & Projected Schedule:

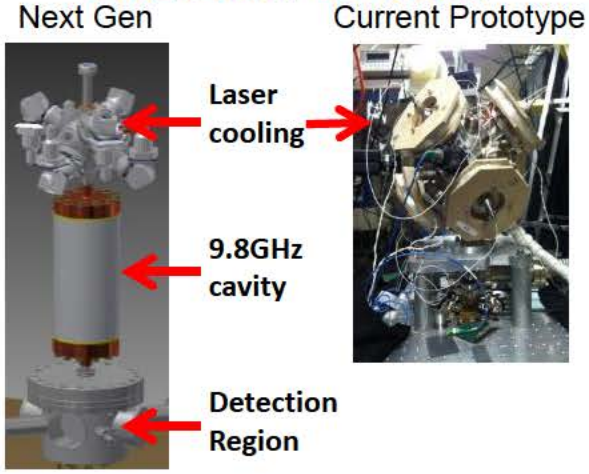
- ~$31M over 3 years
- BAA released April 2015
- Expect multiple contract awards

Advanced Clock Technologies for GPS Spacecraft

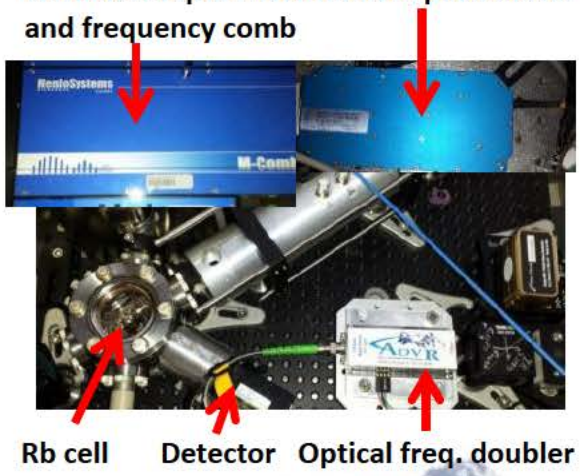
Goal: Develop manufacturable, highly-stable timing for GPS satellites

- **Cold atom atomic clock (cesium)**
  - –Leverage clocks used by NIST & USNO – develop low SWAP, space-compatible version
  - –Addressing manufacturability and reliability
  - –Expect 5X performance headroom over GPS III clocks
  - –Status:
    - Built/ tested more-manufacturable microwave cavity
    - Laser system build – in progress
- **Vapor cell optical clock (rubidium)**
  - –Similar to current GPS clocks, except lamp and OCXO are replaced with manufacturable telecom lasers & Rb vapor cell
  - –Effort began in 2013:
    - Demonstrated 3X performance over GPS III clocks for times less than a few seconds
    - Working to extend useful time and developing packaging options

Cold Atom Cs clock



Optical Rb Clock



OCXO = Oven-Controlled Crystal Oscillator

GPS Military High Gain Antenna

Developing Options for Ground Testing

1) Deployable phased array

- Low profile element
- High efficiency phase shifters at each element
- Leverages legacy payload amplifier and diplexer
- Heritage deployment mechanism

2) Electronically steerable Earth deck array

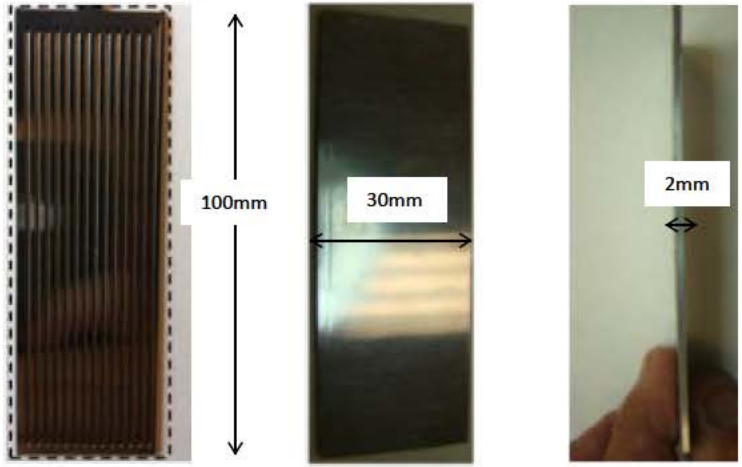
- Features construction modularity and high efficiency
- Minimum S/V mass impact
- Eliminates triplexer and high gain amplifier
- Replaces legacy Earth coverage array

3) Deployable reflector with phased array feed

- Modular 3-step construction
- Minimum assembly tooling
- Passive deployment mechanisms
- Compact composite shell folding scheme

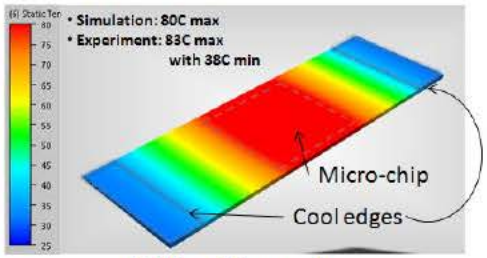
Oscillating Heat Pipe (OHP) Based Chip Carrier

Phase I Moly-lidded OHP Chip Carrier Photos

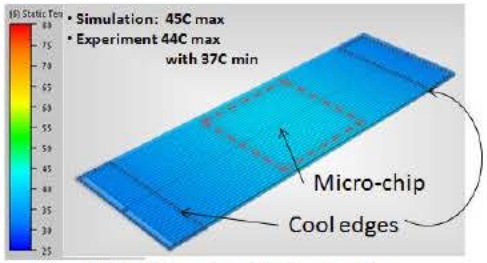


Technical Benefits and Commercialization Potential

- *Durable, coefficient of thermal expansion matched die attach*
- *Ultra-high thermal conductivity*
- *Ideal for high-power/high-flux thermal management*
- *Manufacturable in a variety of materials, fluids, sizes*

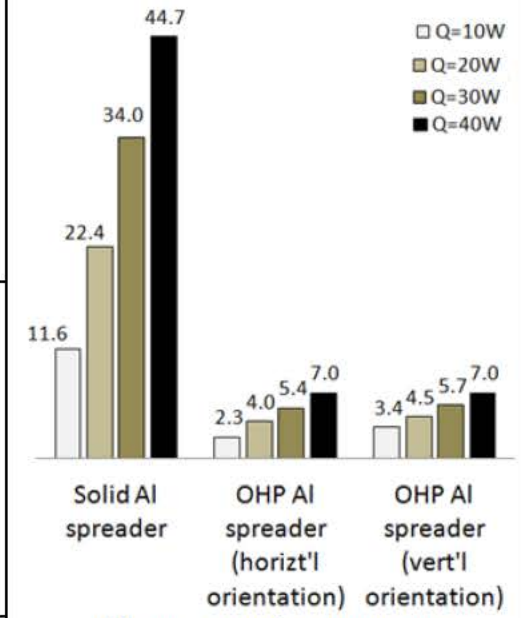


(i) Al-solid spreader



(ii) OHP-embedded spreader

(a) Finite element modeling



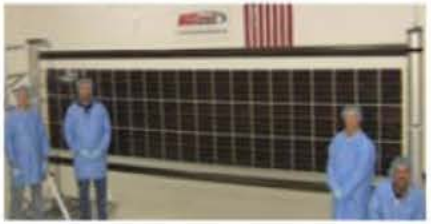
(b) Experimental measurements

ThermAvant Technologies

Array Technologies - ROSA

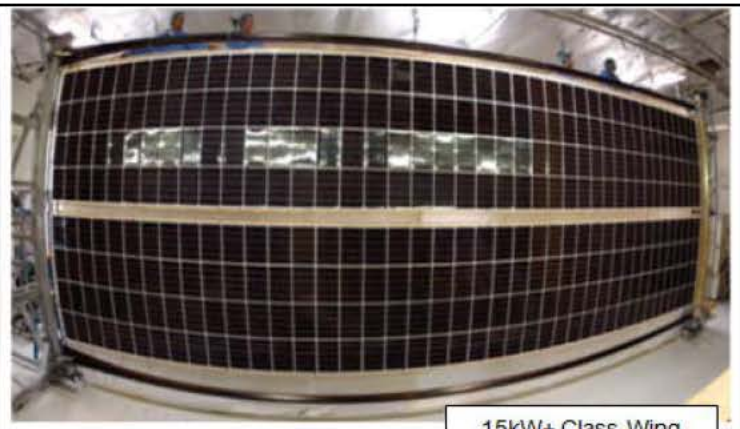
High specific power / lightweight, compact stowage volume and user-friendly profile, broad re-configurability, high strength / stiffness, reliable elastic deployment with no motors or complex mechanisms, modular construction, broad scale-ability, high TRL, affordable / low cost

3kW-6kW Class Wing



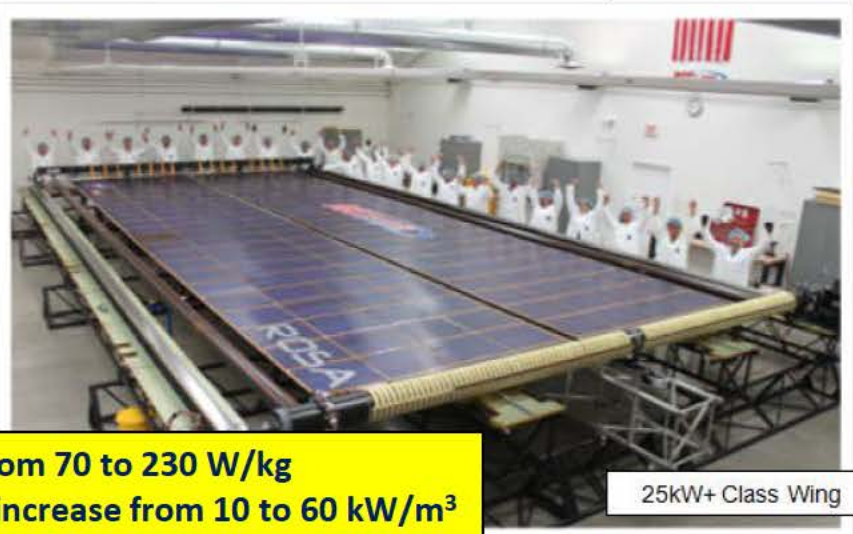
1kW-3kW Class Wing (Retractable)

Patented and Multiple Patents Pending



15kW+ Class Wing

15kW+ Class Wing (Z-Fold Blanket)



25kW+ Class Wing

3x mass savings from 70 to 230 W/kg
6x power density increase from 10 to 60 kW/m^3
4x improvement in wing stiffness

GPS-Focused SBIR Thrust 14.1 Summary

Title	Ph 1 Awards	Ph 2 Awards
Power Aware GPS User Equipment	2	
Secure Time Delivery to Military GPS Receivers Using Existing Wireless Networks	4	
M-Code External Augmentation System	0	Not solicited
GPS Receiver Cryptography Key Delivery Leveraging NSA Key Management Infrastructure	3	
Selective Availability Anti-Spoofing Module (SAASM) Compliant GPS Receiver for GEO	2	Not solicited
GaN Technology for L-Band Power Amplification	4	
Advanced Space Antenna for GPS	4	
L-Band Wide Bandwidth Multiplexer	4	
Radiation-Hardened, Non-Volatile Memory	4	
On Orbit Reprogrammable Waveform Generator	6	
Compact Precision Atomic Clock	2	
Optical System for Clocks and Stable Oscillators	5	
GPS PNT Flexible Satellite	3	
PNT, Comm, Architecture, Mission Design	5	
Disruptive Military Navigation Architectures	11	
Alternative Control Architecture for Residual GPS IIA Spacecraft	0	
Total	59	20

Contracting in process

User Equipment	Payload Components	Clocks	Architecture	Ground System

Developing a Concept for an AFRL Space Flight Experiment

GPS technology ideas under consideration:

Test advanced payload technologies
- Advanced Amplifiers
- ORDWG (Digital Waveform Generator)
- Active array
- Advanced clocks
- High power, directional signals

Ground segment experiments
- Uplink ranging
- Control of hosted payloads

Other Ideas ??

Other potential experiments
- LEO to MEO via electric propulsion
- Advanced User Equipment Concepts

Crosslink experiments

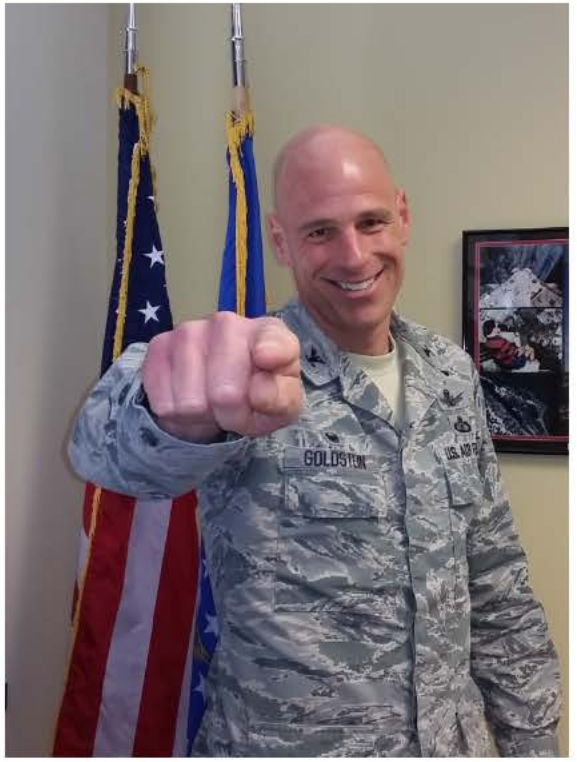
Experiments with alternate signals
- Binary coded signals
- Composite BPSK
- Sinusoidal offset carrier
- Multilevel coded spreading symbols
- Prolate spheroidal wave functions

Also:
- Quantify how well advanced signal generation and transmission meets
  - Current GPS requirements
  - Future needs
- Measure ground systems' performance

Goal: Solidify a GPS experiment concept for consideration as AFRL's next space flight experiment (~2020-2022)

Colonel Goldstein Wants YOU!

- GPS PNT Payload Technology development is a relatively new area for AFRL
- But we plan to make it a long term, core competency
- To that end, we are looking for a few good men/ women who want to explore new GPS PNT Payload technologies and concepts with us!



Interested? Contact me after the briefing or…..

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- Tom Roberts, thomas.roberts.6@us.af.mil, 505-846-7039

Summary

- AFRL is funding a portfolio of science and technology efforts to provide **options** for future GPS spacecraft
  - Working in close partnership with the GPS SPO
- The goal of these efforts is to provide options for:
  - Smaller, less costly space vehicles
  - Performance improvements at affordable cost
  - Flexibility in future spacecraft